GLOBAL MEASUREMENTS OF LOW-FREQUENCY RADIO NOISE

by

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SUMMARY

This final technical report reviews progress in Stanford University's ONR-sponsored global survey of ELF/VLF radio noise (frequencies in the range 10 Hz – 32 kHz) during the period 1 November 1989 through 31 October 1991, i.e., the period covered by ONR Grant No. N00014-90-J-1080, which expired on 31 October 1991.

The research effort during the reporting period consisted largely of (1) the recording of analog and digital radio noise measurements on magnetic tape at up to eight of the recording stations that had been set up around the world prior to the start of the grant period, (2) processing of these measurements to obtain the statistics of the radio noise, and (3) documentation of the radio noise statistics. Large samples of the statistics, from all the measurement sites, were made available to associated researchers at Pacific Sierra Research Corp., who are developing a new ELF/VLF radio noise model (a "Long-wave Noise Model") that will be used by U.S. Navy communicators.

In addition to the above, magnetic field measurements in the ultra-low frequency range (ULF; frequencies less than 10 Hz) were continued at Corralitos, California, in order to characterize the radio noise of most importance to the U.S. Navy's magnetic anomaly detection (MAD) activities. A substantial effort was also made to process and document the Corralitos measurements of anomalous ULF signals that occurred in the month prior to the M 7.1 Loma Prieta earthquake of 17 October 1989, which took place only a short distance away from the Corralitos measurement site during October 1989.

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1. INTRODUCTION

In 1980, in response to the Office of Naval Research's *Research Opportunities Announcement (1980)*, our Laboratory proposed a three-year study of ELF/VLF (10 Hz – 32 kHz) radio noise. This proposal became the basis for ONR Contract No. N00014-81-K-0382 to Stanford University for a study of the global distribution of ELF/VLF radio noise. The starting date for the project was 1 March 1981, its Principal Investigator was Professor R. A. Helliwell, and, after the first year, its Project Director was Dr. A. C. Fraser-Smith. The project originally involved the construction of seven dual-channel computer-controlled ELF/VLF radio noise measurement systems, or 'ELF/VLF radiometers,' and their deployment at various locations around the world to characterize naturally-occurring ELF/VLF radio noise on a global basis. Eight radiometers were ultimately constructed after additional support was provided by Rome Air Development Center, through Contract No. F19628-84-K-0043, and by a DoD Instrumentation Grant, which became ONR Grant No. N00014-84-G-0202. Deployment of these radiometers started during the (northern hemisphere) winter of 1984–1985, when the first system was installed at Arrival Heights, Antarctica, and ended in November 1986 when the final system began recording at Stanford.

A full technical description of the radiometers, details of their geographical locations, and a brief description of the results obtained by some previous radio noise surveys, are given in a paper entitled "The Stanford University ELF/VLF radiometer project: Measurement of the global distribution of ELF/VLF electromagnetic noise," by A. C. Fraser-Smith and R. A. Helliwell, which appeared in *Proc. 1985 IEEE Internat. Symp. on Electromag. Compatability, IEEE Catalog No. 85CH2116–2*, pp. 305–311, August 1985. Further discussion of the project and its results are given in *Fraser-Smith et al.* [1991a].

The original ONR contract for the ELF/VLF radio noise survey was extended until 31 October 1989, when the contract finally expired. However, the noise survey continued with support from ONR Grant No. N00014-90-J-1080, covering the interval from 31 October 1989 through 31 October 1991. Following expiration of this grant on 31 October 1991 the noise survey continued with support from ONR Grant No. N00014-92-J-1576. This final technical report does not therefore describe a project that concluded, but instead it gives a snapshot of the noise survey as of 31 October 1991.

2. RESULTS, 1 NOVEMBER 1989—31 OCTOBER 1991

During the reporting period, our global array of radiometers continued to produce large quantities of analog and digital data on magnetic tapes that were stored at Stanford and which were processed intensively to obtain the noise statistics that are the primary goal of the project. The quantity of data on hand finally exceeded the original plan for the project and to continue their processing in the most efficient manner we were forced to expand the capacity of the magnetic disc storage media linked to our computers. Following a proposal of February 1990, ONR provided additional funds for the purchase of another Digital Equipment Corporation RA81 magnetic disc storage unit for addition to our noise processing computer system. That gave a total of four disc storage units in use.

Soon after the commmencement of the reporting period, it became clear that by October 1991 (the end of the grant period) we would have accumulated at least several years of data from most of the locations where the radiometers were deployed, and in the case of Arrival Heights, where our first radiometer was set up, we would have over six years of data. As a result, it was generally felt that we would have enough data from most locations to ensure the validity of any ELF/VLF noise model. After discussion with our ONR scientific officer, Mr. R. Gracen Joiner, we closed down several of our original eight radiometer stations, keeping the Arrival Heights and Søndrestrømfjord radiometers in operation (high latitude measurements), as well as those at Stanford and Kochi (middle to low latitudes). We were fortunate that our interval of data collection included a solar maximum, and, also fortuitously, a number of large solar particle events (SPE's). Our emphasis toward the end of the reporting period was on the extraction of noise statistics from the data collection and comparison of the statistics with the original 'standard' CCIR data and with the predictions becoming available from the Longwave Noise Model being developed by Pacific Sierra Research with ONR and DNA support.

In addition to the survey of ELF/VLF noise, our laboratory was also very actively involved in measurements of ultra-low frequency (ULF) radio noise during the interval 1989–1991, using new computer-controlled measurement systems that derived half-hour indices of the activity in nine non-overlapping narrow frequency bands covering the overall frequency range 0.01–10 Hz [*Bernardi et al.*, 1989]. These systems were originally developed under ONR's

sponsorship to provide natural background noise information in support of the Navy's MAD operations. However, following our measurement of large-amplitude ULF magnetic field fluctuations prior to the large "Loma Prieta" earthquake that occurred just south of the San Francisco Bay area on October 17, 1989 [*Fraser-Smith et al.*, 1990; *Bernardi et al.*, 1991], there has been pressure on us to expand our ULF measurements to see if we could verify the existence of ULF magnetic field precursors to earthquakes. We then received support from the U.S. Geological Survey (USGS) for the installation of two new systems at Parkfield, California, and then, a little later, for the installation of an additional two new systems in Southern California. A moderately large earthquake was expected to occur at Parkfield at any time (it has still not occurred as of March 1995), and the two locations where the Southern California systems were installed are on fault segments where the USGS believes there is a high probability of large earthquakes. We mention these developments here because they provided us with an array of ULF detectors in California covering a distance of about 500 miles, and the possibility of carrying out Navy-oriented studies of the coherence of ULF noise is compelling.

During the years 1989–1991 we made a substantial effort to document the noise statistics being derived from our collection of noise data. In addition, we provided Pacific Sierra Research (PSR) with large samples of the noise statistics, which we derived specifically to test the Longwave Noise Model being developed by PSR. We were surprised but pleased to find that there was an overall good agreement between our measurements and the predictions both of the earlier CCIR noise model and of the test versions of the PSR model. We had a computer version of the CCIR model and we made extensive comparisons between its predictions and our noise measurements.

Insofar as documentation is concerned, we prepared papers detailing some of the characteristics of the ELF/VLF noise recorded at our Italian and Japanese stations [*Meloni et al.*, 1991; *Fraser-Smith et al.*, 1991b]. In addition, we prepared a more general survey paper, covering our ELF/VLF measurements at all stations [*Fraser-Smith et al.*, 1991a] (see Figure 1 for an example of a display of our noise amplitude data), and a more specifically directed paper detailing the natural noise levels at 50 Hz and 60 Hz [*Fraser-Smith and Bowen*, 1991]. This latter paper contained a comparison of our measurements at 50/60 Hz with those made

by *Maxwell and Stone* [1963] and in the compilation prepared by *Spaulding and Hagn* [1978] (these latter data form the substance of CCIR Report 670 [*CCIR*, 1978], which is the only CCIR report giving noise figures below 10 kHz). The agreement was very good indeed.

We have carried out an extensive study of the occurrence of VLF hiss at high latitudes. This study differed from most of the studies we have carried out as part of the noise survey through its use of the survey's analog noise data, which we usually only inspected to insure the quality of the processed digital data and which we did not normally analyze in any quantity. For our hiss study we prepared spectrograms of all the one-minute/hour synoptic recordings for Arrival Heights, Antarctica, and Søndrestrømfjord and Thule in Greenland that were made during the two month interval February–March, 1987. We then examined each spectrogram to see if there was any hiss apparent on the record, after which we prepared statistics on hiss occurrences for each location. We also carefully examined all examples of simultaneous hiss occurrence at any of the stations. A surprising finding was that no hiss whatsoever was observed at Thule (close to the geomagnetic pole) during the two month interval, even when very strong hiss was occurring at Søndrestrømfjord. Some hiss was observed at Arrival Heights during the two-month interval of the study, but it occurred much less often, and it was weaker, than the hiss at Søndrestrømfjord.

Finally, during 1989–1991 we completed two studies of the ULF and ELF/VLF data we obtained with our ONR measurement systems during the October 17, 1989, "Loma Prieta" earthquake. The first of these studies was a followup to our original article in *Geophysical Research Letters*, and it covered many technical details of the measurements; it appeared in the journal *Physics of the Earth and Planetary Interiors* [*Bernardi et al.*, 1991]. The second study, of the ELF/VLF signals recorded by our Stanford radiometer during five moderate to moderately-large earthquakes, revealed no ELF/VLF signals. This result is of some importance because of French and Soviet proposals to construct and launch a satellite with ELF/VLF receivers that will be used to detect earthquake precursor signals.

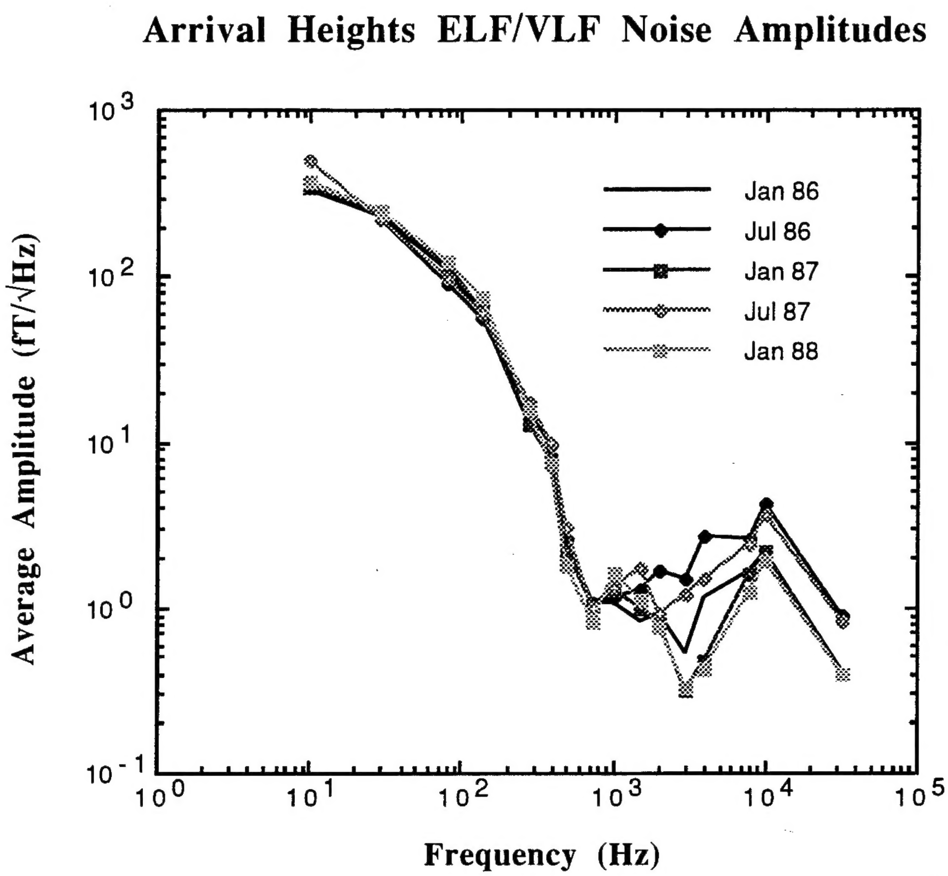

Figure 1. Variation of the Arrival Heights, ELF/VLF noise amplitudes for the months of January 1986, 1987, and 1988, and July 1986 and 1987. Overall average amplitudes for each of the 16 narrow band frequencies are shown. For frequencies less than 1 kHz the amplitudes show little variation over the two year interval.

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